July 30th.

MR. VAUX, Vice-President, in the Chair.

Sixteen members present.

The following was presented for publication:

"Notes on certain Birds from New Grenada, with Descriptions of New Species." By Geo. N. Lawrence.

The following gentlemen were elected members:

Henry C. Gibson, Chas. Gibson, Andrew M. Moore, John Gibson and T. Brantly Langdon.

On favorable report of the Committee, the following paper was ordered to be published:

The Necessity and Velocity of Nebular Rotation.

BY J. ENNIS.

If matter were universally diffused through all space, the supposition would not be in accordance with experience, that this diffusion would be perfectly uniform and even. Such is not the result of natural processes in the actual world. The waters of the ocean are not perfectly uniform; their densities being varied by temperature and saline ingredients. The air is not uniform, nor the vapor of water in the air. Therefore, if matter were universally diffused, and contraction were to ensue, then the rarer portions would gather around the denser, and the expanded vapor would break up into separate huge irregular masses, like the clouds when the vapor of the atmosphere is contracting.

On the surfaces of these separate nebulous masses we can conceive of four sources of motion; the first only hypothetical, and the other three absolutely necessary.

First source of motion. In this general diffusion of matter, the supposition would be unnatural that all was perfectly motionless and still. A state of absolute repose might, for aught we know, be possible, but it would be a strange and unheard of assumption. How unlikely that the causes which spread matter abroad so widely should stop entirely, and leave no motion! Therefore every nebula in its beginning was probably endowed with some movements.

Second source of motion. When separate nebulous masses were formed by the ordinary principles of contraction and condensation, we cannot suppose they would be stationed at equal and symmetrical distances from one another, any more than we see among the white clouds which float together across the clear blue sky. Neither would they be of equal size, for the heavenly bodies, like the clouds, are very unequal in size. Therefore, by the force of gravity, the smaller would fall into the larger; and often two or three near together, though of similar size, would fall into one another. But any one could never fall directly toward the centre of gravity of another; because every approaching pair would be more or less under the influence of other neighboring nebulæ. Therefore, in striking each other obliquely, and not in the direction of their centres of gravity, a rotation must result. These collisions must have been a thousand times more numerous than the fall of meteors now, and so they would continue until space became cleared of all small and neighboring masses, and nothing remained but large and vastly distant nebulæ, each one of which is now represented by a great STELLAR SYSTEM, containing countless numbers of fixed stars.

Third source of motion. By the assumption of the nebular theory, as understood by myself, the contraction of a nebula was always much more slow than would be due to gravity. Therefore gravity would make the nebula round,

and the irregular projections, perhaps long arms, would slide down laterally in the neighboring depressions. By this process many horizontal currents would be produced on the surface.

Fourth source of motion. These irregular projections, perhaps great extended arms but little attached to the nebulæ, would be under the influence of neighboring nebulæ similar to tidal influence and stellar perturbation, especially while the nebulæ were still near to one another, though contracting steadily to greater distances. Therefore the fall of these irregular prominences into the larger mass would be somewhat like the falling together of two independent nebulæ. They would not fall towards the centre of gravity of the principal mass, but more or less obliquely, and hence they would lead to rotatory motion.

From these four sources of motion many currents would flow *on the surface*, at least, of every nebula. In those cases where two large nebulæ fell into each other, the currents would pervade the entire mass. But even when the currents were superficial only, they could not stop; because, on account of the continued contraction of the nebula, they would flow in the direction of an inclined plane. With their horizontal motion they would have an inclined motion towards the centre, and gravity would hasten them downward. These currents would act and react on one another, and by well known mechanical principles they would all result in a single current, as we see by experiment in a basin or funnel of water. This one current would be around the centre of gravity, and, for the same reason, it could not cease to flow. In consequence of the continued contraction of the nebula, every particle of the surface current is moving in the direction of an inclined plane, and gravity must give them the velocity due to inclined plane motion. If they be retarded by friction on the unrotating or slowly rotating interior, then this interior will be moved in the same direction, and gravity will carry it onward until the entire nebula rotates. As the nebula contracts from the extent of its original round form down to near its centre, *every particle must acquire a velocity equal to that of a fall from its original to its last extent*, excepting only the retardation due to friction. This is one of the most essential ideas in the nebular theory originated by myself, and demands a complete illustration.

Every body approaching toward the centre of the sun, whether directly or obliquely, must be hastened by the force of gravity. The celebrated Halley's comet, for instance, which requires about seventy-six years to go around its orbit, is beyond the distance of Neptune when it reaches its aphelion; then the moment it passes its aphelion, and begins its return toward the sun, it begins to be hastened on its course by gravity. So it continues to be hastened by that force every hour faster and faster, during thirty-eight years. Being free to move, and unobstructed, it runs in a conic section, and when it arrives at perihelion its velocity has become so great as to have a centrifugal stronger than its centripetal force. Therefore it shoots away from the sun again, but every hour in its departure its velocity is delayed by gravity. Thus the proposition is certain that when a body departs from the sun its velocity is retarded, and when it approaches the sun its velocity is accelerated, by gravity. Every particle in a current on the surface of a contracting nebula is moving obliquely, like a comet, towards the centre of the nebulous sun, and therefore they must all be hurried along by gravity.

Halley's comet, while descending from aphelion to perihelion, may be regarded as moving down a spiral inclined plane. Its ultimate velocity will be the same as if it had fallen to the sun through the height of the plane, plus its initial velocity at aphelion. That is, its ultimate velocity will be the same as if it had fallen from aphelion in a direct radial line until a distance from the sun equal to its periphelion, plus its initial velocity at aphelion. In the same manner a particle, while descending in its spiral current towards the centre of the nebulous sun, must at any point in its course have the same velocity, friction excepted, as if it had fallen in a direct radial line to that point, plus the

initial velocity which it acquired in the rounding process. I have found by calculation that this velocity may be so great as to give all the zone on the nebular equator a centrifugal force equal to the centripetal force. Therefore a period may arrive in the contraction of a nebula, when the equatorial zone can no longer approach towards the centre, but must be abandoned as a ring circulating around the nebula, until by perturbation it is broken, and subsides by gravity into a rotating nebulous planet. Friction, however, in the cases of some nebulæ, may be so powerful as to retard the velocity, and prevent the separation of matter in the form of a ring.

There are some points of difference between a comet and a particle on a rotating equatorial zone. A comet, in departing from the sun, is deprived by gravity of all that velocity which, in approaching the sun, was imparted by gravity. A nebulous particle does not fly off from the centre like a comet when departing from periphelion, because it does not run in a conic section; and it cannot pursue a conic section on account of friction, which retards its motion, and also on account of atomic repulsion in the nebulous mass, which forces it outside of the elliptic curve on the way towards periphelion. The spiral course of the nebulous particle, from the slowness of nebular contraction, is nearly circular, and hence, when the centrifugal equals the centripetal force, the particle takes nearly a circular orbit. Hence, as it always approaches the centre of the nebulous mass, it always receives velocity from gravity. And when it ceases to approach, it never flies far off, and therefore never loses velocity from gravity, as does the comet.

Gravity could cause no rotation, unless a particle on the surface had first a horizontal motion given in the process of rounding the nebula, and unless the nebula contracted. By this horizontal motion and by contraction, the particle approaches the centre of the nebulous sun obliquely, and gravity hastens it down the inclined path. The particle cannot stop, because there is nothing to make it stop. Repulsion cannot stop it, because repulsion, like centrifugal force, is *every instant yielding before it*, and allowing it to retain all its actual motion, and to acquire more motion *by a fall every instant* towards the centre. If it be delayed in its velocity by friction on other particles, then just so much momentum must be imparted to them, and they too will move in the direction of an inclined plane towards the centre, and these again will move other particles, and so on until the entire mass moves and rotates. If the particle had no horizontal motion, then repulsion and gravity would act upon it in opposite directions, and it would partake only of the general contraction in radial lines towards the centre. There could be no rotation. But by its horizontal motion, and by the slow contraction of the mass,—slower than is due to gravity,—the particle finds the path before it every instant settling down. Hence *every instant it goes down as it goes forward*, and its motion is in the direction of an inclined plane, and subject to the inclined plane law of increased velocity; that is, a velocity equal to that of a fall through the height of the plane.

Imagine a circle, the equatorial section of a nebulous globe, with a million of radii. Then the particle with a horizontal motion finds at each succeeding radius that the surface, by contraction, has gone down towards the centre. It must, through gravity, follow that surface downward. Every instant, therefore, it receives a new impulse down its course,—a million of impulses in one revolution. Then, with no impulse in the contrary direction, its velocity must increase.

By calculating the velocity of the equatorial zone of our sun down an inclined plane as due to gravity, I ascertained the velocity of rotation of our sun when in a nebulous condition, and found that it precisely equalled, at different stages of its contraction, the present velocities of the planets and asteroids when an infinitessimally small allowance is made for an inevitable friction on the unrotating or slowly rotating interior. These small allowances due to friction are given in my recent volume, "The Origin of the Stars." In that volume also the rotations of the several nebulous planets are shown to have

been the same as the present revolutions of their satellites; and the reason is pointed out why the smaller planets could have no satellites. By these and by many other coincidences the discovery was first made that GRAVITY IS THE FORCE WHICH IMPARTED ALL THEIR MOTIONS TO ALL THE STARS.

It is proper now to attend to three objections which, on account of the present state of astronomical science, naturally rise against this view of the necessity and velocity of nebular rotation.

The first objection is that this view "contravenes the principle of conservation of areas." The fallacy of this objection may be seen by a very simple arithmetical calculation. We will take Mercury, whose radius vector moves most rapidly, and at the rate of 110,000 per hour. Neptune is about eighty times farther from the sun. The original extent of our nebulous sun was halfway to the nearest fixed star; say 3,622 times farther than Neptune, and consequently, in round numbers, $3622 \times 80 = 290{,}000$ times farther than Mercury. The area described by the radius vector of Mercury in one hour equals that radius multiplied by half its distance per hour, say $1 \times 110{,}000 \div 2$. The area described by the radius vector of the original nebulous sun must have equalled that radius multiplied by half its distance per hour, say $290{,}000 \times x \div 2$. Both these areas must be equal. Now what must be the value of x that, when multiplied by 290,000, gives 110,000? Plainly $\frac{1}{2}\frac{1}{9}$, or $\frac{1}{3}$ nearly; that is, the movement of the radius vector of the original nebulous sun, or, in other words, its primary rotation, was about one-third of a mile per hour. I will soon point out how this velocity was obtained.

The second objection is drawn from a misapplication of the principle that action and reaction are equal, and in opposite directions. By this principle, when an object falls to the earth, the earth falls proportionally to the object; when we walk forward in a straight line, we push the earth backward proportionally; when a car, by gravity, runs down an inclined plane, the earth as well as the plane moves proportionally in the opposite direction: that is, both upward and backward. Therefore it has been wrongly inferred that when a particle, or all the particles, on the rotating exterior of a contracting nebula move by gravity in the direction of an inclined plane toward the centre, then the interior should move proportionally just the contrary way. It has been wrongly inferred that these two opposite motions should counterbalance each other, that in fact there can be no such operation, that the whole idea is like "the old absurdity of a perpetual motion, or of a man trying to lift himself up by pulling at the straps of his boots."

But all such inferences show a misunderstanding of the case. We must learn to see the difference between moving in the direction of an inclined plane, and moving on an actual inclined plane. A comet or a planet approaching perihelion is moving in the direction of an inclined plane. With its forward motion in its orbit it has an inclined motion towards the sun, and its velocity is hastened by gravity in consequence of this inclination. Imagine a hundred comets all in the plane of the sun's equator, and equally distributed around the sun, and all approaching their perihelion. While all would be accelerated by gravity toward the sun, the sun would not be moved in any way towards them, because it would be equally acted on all around by the comets. Neither could there be any reaction to make the sun rotate in the opposite direction, because there is no actual inclined plane to cause a backward motion. The comets have the inclined plane motion without an inclined plane. In the same manner on the horizontal equatorial zone of a rotating and contracting nebula, all the particles move in the direction of an inclined plane spirally coiled many times around, and all are hastened by gravity according to the law of velocity on such a plane, but not one of them moves down an actual inclined plane. THEY ALL REPOSE ON A LEVEL OR HORIZONTAL SURFACE! therefore they do not move the interior backward while they move forward. If they were on an actual inclined plane they would create a coun-

ter movement. But such is not the case. Each one, while approaching the centre, draws the entire mass up towards itself, as when a fly alights on the earth, but being equally distributed all around, they counteract one anothers' efforts in this regard, and produce no result. The reason why there is a backward reaction on a real inclined plane is simply because of the inclination of the surface. An object cannot repose quietly on such a surface. The forward motion of the object must give a backward push to the surface. But when there is no inclined surface, as on an equatorial zone, there can be nothing against which a backward push can be made by mere gravity.

In its approach toward perihelion a comet is upheld from falling in a straight line toward the sun by centrifugal force; that is, its plane is sustained by centrifugal force. In like manner, on the equatorial zone of a rotating and contracting nebula, a particle is upheld from falling straight toward the sun's centre, partly by centrifugal force and partly by atomic repulsion; that is, its plane is upheld partly by centrifugal force and partly by repulsion. But neither of these hinders the force of gravity from imparting every instant an increased velocity in the inclined plane direction. Both repulsion and centrifugal force are constantly yielding before the power of gravity, and allowing the comet or the particle to be accelerated. In this way inclined plane direction and increasing velocity are produced without an actual inclined plane, and hence one of the reactions of an inclined plane is wanting: namely, the backward reaction. The other reaction—the upward—is nullified by opposite particles on opposite sides of the nebula.

Atomic repulsion has two effects different from mere centrifugal force; it hinders the moving particle from following an elliptic orbit, and it causes retardation by friction. But the direction of its action is always in a radial line, always perpendicular to the nebular surface on which the particle quietly reposes; and it yields every instant like centrifugal force before the power of gravity, which continually brings the particle toward the centre. In the beginning of nebular rotation, and when that rotation is very slow, a particle on the exterior presses with nearly all its weight on the interior. It is then upheld very little by centrifugal force, and chiefly by repulsion. As it moves more rapidly it acquires greater centrifugal force, and presses less heavily on the interior. It becomes hourly less and less upheld by repulsion, and more and more by centrifugal force. At length it is held up entirely by centrifugal force, and presses no more on the interior. It is independent of repulsion; it circulates freely around the centre, without approaching it. The centripetal and the centrifugal forces are equal.

An important illustration may be made with a funnel to show that a fluid may move down the direction of an inclined plane without producing the backward reaction of such a plane. Suspend the funnel by a single small silk braid, having no twist. Pour in the water, and give a portion a horizontal motion. Give the funnel an equal impulse in the opposite direction. The water, as it runs through the funnel, will rotate, and evidently every particle of the water will run an inclined plane direction, but the plane must necessarily take the form of a coil. According to the principle of the backward reaction on an actual inclined plane, the natural expectation would be to see the funnel rotate in the direction contrary to that of the water. But this does not occur. On the other hand, the water, by friction, carries the funnel around in the same direction with itself. In like manner the exterior of a nebula must carry along the unrotating interior with its own motion. The reason is the same in both cases. There is no backward reaction, because in both cases the particles, as they move, REPOSE ON A HORIZONTAL SURFACE. They do not move down an actual inclined surface, and hence cannot react according to the law of an inclined plane surface. They have the law of velocity, but not the law of backward reaction. This absence of the backward, though not of the upward, reaction, may be regarded as a new dynamical principle. It has not before been detected in the funnel problem, nor in the nebular theory, nor in aught else that I am aware.

The third and last objection is that gravity cannot cause nebular rotation, and that it cannot therefore be the force which imparted their present motions to the stars. We have already seen that if, on the surface of the nebula which formed our solar system, there had been a movement of rotation only about one-third or one-half a mile per hour, then gravity, acting by the law of conservation of areas, would have imparted the velocity of 110,000 miles per hour to Mercury. But how could this nebula have received a rotation of half a mile per hour? This question is easily answered by following the logical consequences of the nebular theory, aided by well known facts in astronomy. The fixed stars have velocities at least equal to the planets. When they were all in a nebulous condition, just broken up from the vast nebulous disk stretching all around within the Milky Way, they must have been irregular in form, quite near to one another, and *endowed with their present rapid velocities.* Then, by their mutual perturbations, they must have imparted motions to one anothers' irregular exteriors.

The power of perturbation between the fixed stars is much stronger than has been suspected by astronomers. In "The Origin of the Stars" I have shown that the sun's gravity on Alpha Centauri is now so powerful that that star must move more than 2,000 miles per day at right angles to its present direction from ourselves, to gain a centrifugal force sufficient to avoid falling into the sun. Estimating the masses of the stars from the amounts of their light and their distances, then the power of gravity from Alpha Centauri alone on our sun is so great that our sun must move more than 5300 miles per day to avoid falling into that star; and for the same reason our sun must fly with a velocity of more than 13,000 miles per day to avoid falling into Sirius. When these stars were in their nebulous conditions, expanded nearly to one another, irregular in shape, and moving past one another with their present astonishing velocities, their mutual power for moving currents on their irregular surfaces must have been very strong. Moreover, they must have had the same liability to fall into one another, and thus to produce rotation as the original stellar nebulæ.

We can also readily conceive how, in the very first formation of the several solar nebulæ, and flying along with inconceivable rapidity, their irregular projections may not have had precisely the same motions as the centre of gravity. From all these causes we can understand how, after the rounding process, a motion of half a mile per hour may have been given to the one resultant current on their surfaces.

But whence the proper motions of the fixed stars? or rather, whence the proper motions of the nebulæ from which the fixed stars were formed? The nebular theory gives the same cause for the forms and the motions of the stellar systems as of our solar system. That theory points to a great original nebula, whose rotations by the force of gravity formed and moved the ring of the Milky Way, and its interior disk, and its scattered exterior clusters. Gravity, in causing this rotation and the proper motions of the fixed stars, must have acted by the law of conservation of areas; and now we must inquire how much motion, according to that law, was necessary on the surface of our original stellar nebula? If half a mile per hour was sufficient for our solar system, how much was necessary for our stellar system? On the supposition that the stellar motions are as rapid as the planetary, and that the force of gravity was equally strong in both, then the original surface motions of our solar and stellar nebulæ must have been to each other in some proportion inversely as the lengths of their radii. But as the length of the stellar radius was almost infinitely longer than that of the solar radius, so the original motion on the surface of the stellar nebula must have been almost infinitely slower than on the surface of the solar nebula; that is, almost infinitely slower than half a mile per hour!

But whence these very slow motions on the surfaces of the original stellar nebulæ? These I have already given in the four sources of motion in the beginning of this paper.

In our solar nebula the areas described by the radius vector diminished very slowly, on account of the very slight friction, which also retarded the velocities of the planets, as I have shown in Section 19th.

August 6th.

MR. CASSIN, Vice-President, in the Chair.

Nineteen members present.

Dr. H. C. Wood, Jr., called the attention of the Academy for a few minutes to some observations on the life history of some of our siphonaceous fresh water algæ.

He stated that the accounts of the method of the production of the zoospores of the ordinary *Achyla prolifera*, as given by Henfrey and Carpenter, differed very essentially. The former states that the zoospores do not directly appear in the filaments, but that in the original zoosporangium are formed only *daughter cells* by the aggregation of nitrogenous protoplasm, which daughter cells are incapable of spontaneous motion, are unprovided with cilia, and are emitted apparently by being, as it were, forced out by endosmotic pressure excited through the zoosporangium. After emission, according to Henfrey, they remain clustered at the end of the filament, and in a few hours each daughter cell gives origin to a single zoospore, which is formed from the whole of its protoplasmic contents. According to Carpenter, the zoospores are formed directly in the zoosporangium, are then furnished with cilia, and escape by means of their own motile power. Dr. Wood stated that his own observations on the plant entirely corroborate and coincide with the results arrived at by the lamented Henfrey, and that he had frequently seen the very delicate cellulose coats of the daughter cells still aggregated around the distal end of the zoosporangium after the escape of the zoospores from them. Dr. Wood further called the attention of the members to the existence of several algoid forms growing in the neighborhood of the city, which were closely allied to *Achlya prolifera*, but in some respects quite distinct from it. In one of these, which appears to be at least generically the same as the former species, the Doctor stated he had studied the formation of *resting* spores, which takes place in a way similar to that seen in other of the Siphonaceæ, such as the Vaucheria. At the distal end of a filament about to form resting spores a roundish bulb-like enlargement takes place, which soon is crowded with nitrogenous protoplasm derived from the main filament, from which it is in a little while shut off by a delicate membranous partition. About this time, just below such sporangium, there appears a process very similar to that seen in the Vaucheria, which process finally comes in contact with the sporangium, between which and itself a communication is soon established. The contents of the sporange now contract themselves into a globular ball, and develop into the resting spore.

If these views and observations hereafter should be confirmed, they would settle the doubt expressed by many authorities, whether the Achyla be not merely a submerged fungus, altered by this very submersion so as to resemble an algoid growth; for if species of the genus are found whose whole life history is similar to that of others of the Siphonaceæ, even to the formation of resting spores by a kind of conjugation, it seems indisputable that the organisms under consideration are perfect entities, not merely degraded forms of higher plants. Further, granting the facts stated, if one of the Siphonaceæ is a fungoid growth, surely all the others must be; and it does not seem probable that the Vaucheria, with its green endochrome, is a fungoid growth.

Dr. Leidy mentioned the recent appearance of the seventeen year locust in Montgomery, Wythe and other counties of Virginia.